STANDARDIZED VISUAL COUNTS OF GOLIATH GROUPER OFF SOUTH FLORIDA AND THEIR POSSIBLE USE AS INDICES OF ABUNDANCE

by

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Introduction

Goliath grouper, *Epinephelus itajara*, is the largest grouper in the western North Atlantic and one of the largest groupers in the world (Heemstra and Randall 1993). It is an unwary species that congregates predictably on artificial wrecks and reefs, making it especially vulnerable to fishing. Not surprisingly, it was overfished through the 1980s. All harvest of goliath grouper was prohibited in the U.S. Gulf of Mexico by emergency rule in 1990 (GMFMC 1990). Harvest was also banned in U.S. Atlantic and Caribbean waters in 1990 and 1991, respectively (Sadovy and Eklund 1999). The recovery of goliath grouper has been slow due to its long-life span and low reproductive rate (Sadovy and Eklund 1999). Nonetheless, anecdotal reports from fishers and divers suggest populations are increasing in U.S. waters.

The NOAA-Fisheries Southeast Fisheries Science Center is currently assessing the status of the goliath grouper stock and developing estimates of its recovery time. Traditional fishery-dependent data are of little use in this endeavor inasmuch as they extend back only a few years prior to the closure and are probably inaccurate (SEDAR 2003). There are, however, two visual surveys that may prove more helpful: the personal observations of a professional spearfisher (DeMaria[1]) and a volunteer fish-monitoring program administered by the Reef Education and Environmental Foundation (REEF 2000).

Sadovy and Eklund (1999) constructed an index of abundance from the DeMaria survey but did not account for the unbalanced design of the sampling procedure. An inspection of the data revealed that the counts of goliath grouper differed among locations (Figure 1) as well as with the onset of the spawning season in late summer/early fall (Figure 2). When coupled with uneven sampling, either situation could bias the overall trend. A similar situation occurs with the

[1] DeMaria, Don. P.O. Box 420975, Summerland Key, FL 33042.

REEF data, but the matter is complicated further by the fact that the observations of 3 to 10 fish are recorded only as 2 or more. In this paper we standardize both surveys by use of generalized linear models (GLM) that compensate for the unbalanced design of each survey and, in the case of the REEF data, account for the fact that the data are censored at 2.

Methods

Field data collection: DeMaria Survey

The protocol adopted by Mr. DeMaria was to count the total number of goliath grouper he encountered on specific sites during SCUBA dives that would typically last 25 minutes (due to diver-depth limitations). Prior to 1990, he was spearfishing and he recorded the number of fish observed as well as the number speared. After the moratorium began in 1990, he continued to visit these sites with researchers and recorded the number of fish seen on his dives. Due to the size of the fish (1-2 m in length) and the discrete area of artificial sites (all of the reef fish, including the goliath grouper, typically are concentrated at the structures and not found for the most part in the adjacent sand areas), it was not difficult for him to count all fish on a particular site, particularly if there were fewer than 50 individuals. Researchers diving with Mr. DeMaria found that his counts differed little from their own. However, Mr. DeMaria has stated that the numbers recorded during the early years may underestimate the actual number on each site since there were many more fish to count at that time.

The specific locations included in Mr. DeMaria's survey are indicated in Figure 3. They include (1) the wreck of the Baja California, a WWII merchant marine ship sunk 40 miles north of Key West in about 36 m of water, (2) the wreck of a small shrimp boat approximately 90 miles north of Key West at a depth of 34 m, (3-4) the stern and bow sections of a Patrol Boat about 2 miles north of site 2 in 40 m and (5) a Navy navigation tower about 2 miles from site 1 in 30 m of water. Sites 1 and 5 are well known and frequently visited by divers and fishers. Sites 2, 3 and 4, on the other hand, were seldom visited by other fishers or divers. Several dives were made on each site during most years, particularly early in the time series.

Field data collection: REEF Survey

The REEF database has been constructed from a compilation of the observations of volunteer divers trained in the roving diver technique (Pattengill-Semmens and Semmens 1998, Jeffrey et al. 2001). Essentially, divers swim freely about a dive site within a 100 m radius of the starting point, recording every species that they can positively identify. After the dive they assign an abundance category to each species: (1) a single fish, (2) 2-10 fish, (3) 11-100 fish or (4) > 100 fish. The dive location, dive duration, depth, bottom temperature, visibility, habitat type and experience level of the diver are also recorded.

The data provided to us included 15890 surveys conducted at 903 dive sites from June 1993 through 2002. Sites where goliath grouper were never observed and sites visited in fewer than 6 different years were culled from the analysis, leaving a total of 5246 surveys at 32 sites (see Table 1). Most of the sites that made the cut are located in the Florida Keys, the rest being located along the Florida east coast (Figure 3). The primary habitat types recorded for these sites were: (1) mixed, meaning a variety of individual habitats; (2) high profile reef, where coral structures rise > 1.3 m off the bottom; (3) low profile reef, where coral structures rise < 1.3 m off the bottom and (4) artificial structures, including ship wrecks and other dumped debris. On a few occasions some of these sites were also reported as rubble, sloping dropoffs, ledges, or shear dropoffs. In such cases rubble and sloping dropoffs were counted as mixed habitats while ledges and shear dropoffs were counted as high profile reefs.

Statistical modeling: DeMaria survey

The number of goliath grouper spotted on a given dive (N_i) at location L during year Y and season S was assumed to be lognormally distributed such that

(1) $\ln(N_i+c) = \alpha + \beta_Y + \beta_S + \beta_L + \beta_{YS} + \beta_{YL} + \beta_{SL} + \varepsilon_i$

where c is a small constant (1.0) added to allow for occasional zero counts, ε is a normally-distributed error term, α is the intercept parameter, and the β are categorical variables that represent the main effects and second-order interactions corresponding to each year, season and location. There were insufficient data to estimate a third order interaction (β_{YSL}). The categorical variable for season included two levels; one for observations made during the warm season (June – October) and the other for observations made during other times (there were insufficient observations to subdivide this further and the designation June–October provided the best fit to the data).

A stepwise approach was used to build a parsimonious statistical model. The procedure was initiated by constructing competing GLM's (SAS 1993) each consisting of a base model (the year main effect alone) plus one of the remaining categorical variables. The variable that most reduced the deviance per degree of freedom was then added to the original base model, provided it was statistically significant according to the sample-size-corrected version Akaike's information criteria (AICc, Hurvich and Tsai 1995). This process of adding factors one at a time and updating the model with the categorical variable that most reduced the deviance per degree of freedom was repeated until no factor (main effect or interaction) met the criteria for incorporation into the final model. After the final model was identified, it was fit to the proper response variables using the SAS macro GLIMMIX (c/o Russ Wolfinger, SAS Institute Inc.). All main effects and interactions were treated as fixed effects except year interactions, which were treated as random effects, so that annual indices of abundance could be constructed with variances that appropriately reflect the added uncertainty expected when significant year interaction effects are present.

The standardized measure of visual counts for year Y was computed as

$$N_Y = \exp\{ \alpha + \beta_Y + (d+1)(s^2_R - s^2_{ln(\alpha\beta)})/2d \} - c \tag{2}$$

where the values used for $\alpha + \beta_Y$ are the GLM estimates (see Bradu and Mundlak 1970, Gavaris 1980). The terms s^2_R, d, and $s^2_{ln(\alpha\beta)}$ are the estimated residual variance, the degrees of freedom for the residual variance, and the estimated variance of $\alpha + \beta_Y$, respectively.

Statistical modeling: REEF survey

The relative rarity of goliath grouper in the REEF samples coupled with the fact that observations of multiple animals are recorded as "2" suggests that the count data are unlikely to follow a lognormal distribution. One alternative is to treat the series as presence-absence data and model the proportion of surveys with positive counts, but this method would ignore some of the information content in the data. Instead, we model the counts using the censored Poisson distribution:

$$(3)\ p(N) = \begin{cases} \dfrac{e^{-\mu}\mu^N}{N!} & x = 0, 1, \ldots, Z-1 \\ 1 - \displaystyle\sum_{k=0}^{Z-1} \dfrac{e^{-\mu}\mu^N}{N!} & x \geq Z \end{cases}$$

where Z is the censor point and μ is the expected count of goliath grouper. In the present case the censor point is 2, therefore maximum likelihood estimates for the parameters α and β may be obtained by minimizing the negative loglikelihood expression

(4) $$L = \sum_{N_i=0} \mu_i + \sum_{N_i=1} (\mu_i - \ln \mu_i) - \sum_{N_i=2} \ln\left(1 - (1 + \mu_i) e^{-\mu_i}\right)$$

The expectation for a given dive, μ_i, was modeled as

(5) $$\ln\mu_i = \gamma_t + \alpha + \beta_Y + \beta_S + \beta_L + \beta_E + \beta_V + \beta_H$$

where the γ_i is the offset covariate (dive duration) and the β are categorical variables representing the main effects of year, season, location, experience level, visibility and habitat type, respectively. There were two levels for season (June–October, November-April), three levels of visibility (poor, fair and good), two levels of experience (novice or experienced) and four levels of habitat (described above). The most parsimonious combination of main effects was identified by use of the AICc criteria. Interaction effects were not estimated owing to the sparseness of the observations at many of the sites.

All model fits (negative loglikelihood minimizations) were accomplished using the utilities provided in the software package AD Model Builder[2]. Standardized measures of visual counts for each year were constructed as

(6) $$N_Y = \exp\{ \alpha + \beta_Y \}.$$

Confidence limits for N_Y were obtained by the likelihood profile method.

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[2] AD Model Builder Version 6.0.2. Otter Research Ltd., Box 2040, Sidney, B.C. V8L 3S3, Canada.

Results

DeMaria survey

The main effects associated with year, location and season were all statistically significant; accounting for 27%, 22% and 2% reductions in deviance per degree of freedom, respectively. The year/location interaction term was also statistically significant and therefore was included as a random effect. The log-scale residuals followed closely those of a normal distribution with constant variance (Fig. 4), verifying the underlying lognormal error assumption of the final model.

The standardized index of goliath grouper counts is similar to the time series of annual means (Table 2, Fig. 5). The wide error bars are largely a result of the high variability and low replication, but also reflect the significant year/location interaction. Nevertheless, the initial decline and post-1990 increase in goliath grouper counts is statistically significant.

REEF survey

The main effects associated with year, location, and season proved statistically significant. There was no discernible relationship between the number of goliath grouper counted and dive duration; incorporating dive duration as a covariate significantly degraded the model fit according to the AICc. The fit of the model was poor, accounting for only about 7 percent of the variation in the data. Accordingly, the standardized index is very similar to the time series of annual means (Table 2, Fig. 6). As was true for the DeMaria survey, the wide error bars are largely a result of the high variability and low replication. Nevertheless, the estimated increase in abundance is statistically significant.

Discussion

The most important factors in standardizing the DeMaria and REEF data were the year and location. The seasonal effect was also statistically significant, but it had relatively little impact on the percent of the variation explained by either model because most of the dives in any given year were conducted during the 'warm' season. In the case of the DeMaria survey, the estimates for the seasonal effects suggest that the abundance of goliath grouper on the five artificial reefs is about 50% higher during the 'warm' season than during the 'cold' season. Anecdotal observations (Sadovy and Eklund 1999) as well as the recent results from an acoustic tag study (Figure 7) appear to support this conclusion. However, exactly the opposite trend is estimated from the REEF survey data; goliath grouper appear to be about 50% less abundant during the warmer months. It is possible that the reversed trend in the REEF data is spurious owing to the present scarcity of goliath grouper observations in those areas. Nonetheless, it is possible that the opposing trends reflect summer movements related to spawning or seaward migrations during the cold winter months.

The large size and generally unwary nature of goliath grouper makes them easy to spot, even under relatively poor visibility. Hence, it is not surprising that visibility and diver experience were not significant factors in the analysis of the REEF data. Furthermore, inasmuch as the range examined by each diver is limited by design to a 100 m radius, conspicuous fish like goliath grouper are likely to be seen shortly into the dive, which explains why the number counted was independent of dive duration.

The standardized DeMaria and REEF surveys can be used as measures of the relative abundance of goliath grouper off southern Florida. In the case of the DeMaria index such extrapolations are somewhat tenuous owing to the relatively restricted geographic area surveyed and the apparently limited movements of adult goliath grouper (Smith 1976). Mr. DeMaria and others assert that these offshore sites were the last of the known goliath grouper aggregations to be exploited and had not been subjected to the decades of fishing pressure that inshore area had experienced (DeMaria, pers. comm., Gladding pers. comm., SEDAR report). In other words, the high abundance of goliath grouper on these artificial sites in the early 1980's did not reflect the overall depleted state of the rest of the resource. Moreover, the rapid declines observed at sites 1, 2 and 4 in the early 1980's were largely due to heavy fishing pressure exerted at about the time the survey began (DeMaria[1]). Since as these wrecks were easily relocated, once they had been discovered, and harbored high concentrations of goliath grouper, they probably received proportionately more fishing pressure than the population as a whole. Hence, it is likely that the initial decline indicated by the index is more precipitous than that of the overall population.

The REEF survey includes many more sampling locations (32) and is spread over a much broader area than the DeMaria survey; therefore it is probably a reasonably good index of the relative abundance of goliath grouper along the southeast coast. Unfortunately, the center of abundance of the goliath population is along the southwest coast (as evidenced by the very low numbers seen at all REEF sites). The REEF and DeMaria surveys both indicate a substantial increase since the 1990 moratorium on harvest, but the increase in the REEF survey does not begin until several years later (Figure 8). This delay in recovery along the east coast, relative to the increase in the west coast, may be to a lack of nursery habitat along Atlantic shores or a concentration effect on artificial structures in the Gulf of Mexico. Anecdotal reports reveal that this species was historically observed frequently along both coasts of southern Florida (Eklund 1994; DeMaria 1996).

Despite the above misgivings, the surveys in question are the only such time series available for adult goliath grouper. As such, they are invaluable to any attempt at assessing the status of the resource. In this regard, the counts made after the harvest moratorium imposed in 1990 should prove especially useful as an indicator of the rebuilding potential of the stock. The most troubling aspect, the very rapid initial decline in the DeMaria index associated with local depletion, may be handled simply by ignoring the data prior to 1984.

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Table 1. Sites in the Reef Education and Environmental Foundation database used for this analysis, with the number of surveys conducted at each site between 1994 and 2002 and the total number of goliath grouper observed (observations of “2 or more” were counted as 2).

Location	REEF Geozone	Number of goliath grouper	Number of surveys	Number of years
Juno Ledge	33010005	2	15	7
Opal Tower	33010038	4	47	6
Delray Ledge	33010042	2	15	6
Anchor Chain	34030001	1	152	9
South Ledge	34030003	1	117	9
Grecian Rocks	34030004	2	295	9
Key Largo Dry Rocks	34030005	1	296	9
Carysfort Reef	34030006	1	145	8
South Carysfort Reef	34030007	1	75	8
French Reef	34030008	3	374	9
Molasses Reef	34030009	24	942	9
Benwood Wreck	34030011	7	172	9
City of Washington	34030014	3	134	9
Horseshoe Reef	34030018	9	67	9
NN Dry Rocks	34030023	1	175	9
The Elbow	34030031	4	82	9
Alligator Reef	34040002	1	131	6
Conch Reef	34040004	4	207	9
Tennesse Reef	34040008	2	93	7
Sombrero Reef	34050001	6	192	9
Samantha’s Ledge	34050002	2	113	8
Looe Key Reef East	34050005	10	183	7
Looe Key Reef	34050006	5	75	7
Western Sambo	34080001	9	297	9
Eastern Sambo	34080002	6	108	8
Rock Key	34080003	3	129	9
Sand Key	34080004	2	195	9
Middle Sambo	34080005	1	99	8
Western Dry Rocks	34080018	1	123	7
Texas Rock	34100004	7	100	7
Pulaski	34100005	2	76	6
Windjammer site	34100015	11	22	6

Table 2. Relative standardized count index for goliath grouper from two diver surveys in southern Florida waters.

YEAR	RELATIVE INDEX	LCI	UCI	CV
		DeMaria survey		
1982	4.43	2.30	8.51	0.34
1983	0.99	0.50	1.96	0.35
1984	0.87	0.47	1.61	0.32
1985	0.45	0.26	0.78	0.29
1986	0.23	0.12	0.44	0.33
1987	0.19	0.09	0.40	0.37
1988	0.35	0.18	0.69	0.35
1989	0.13	0.06	0.27	0.40
1990	0.22	0.09	0.53	0.45
1991	0.27	0.12	0.62	0.44
1992				
1993	1.18	0.40	3.43	0.58
1994	1.13	0.54	2.34	0.38
1995	0.89	0.47	1.69	0.33
1996	0.77	0.42	1.38	0.30
1997	1.52	0.76	3.07	0.36
1998	1.83	0.80	4.14	0.43
1999	0.91	0.47	1.76	0.34
2000	0.41	0.15	1.11	0.53
2001	1.63	0.83	3.20	0.35
2002	1.63	0.77	3.43	0.39
		REEF survey		
1994	0.26	0.04	0.49	0.46
1995	0.00	0.00	0.01	0.46
1996	0.25	0.00	0.81	0.99
1997	0.95	0.38	1.64	0.30
1998	1.51	0.69	2.47	0.26
1999	0.93	0.32	1.57	0.32
2000	2.02	1.14	2.86	0.19
2001	1.31	0.77	1.83	0.19
2002	1.77	1.14	2.41	0.16

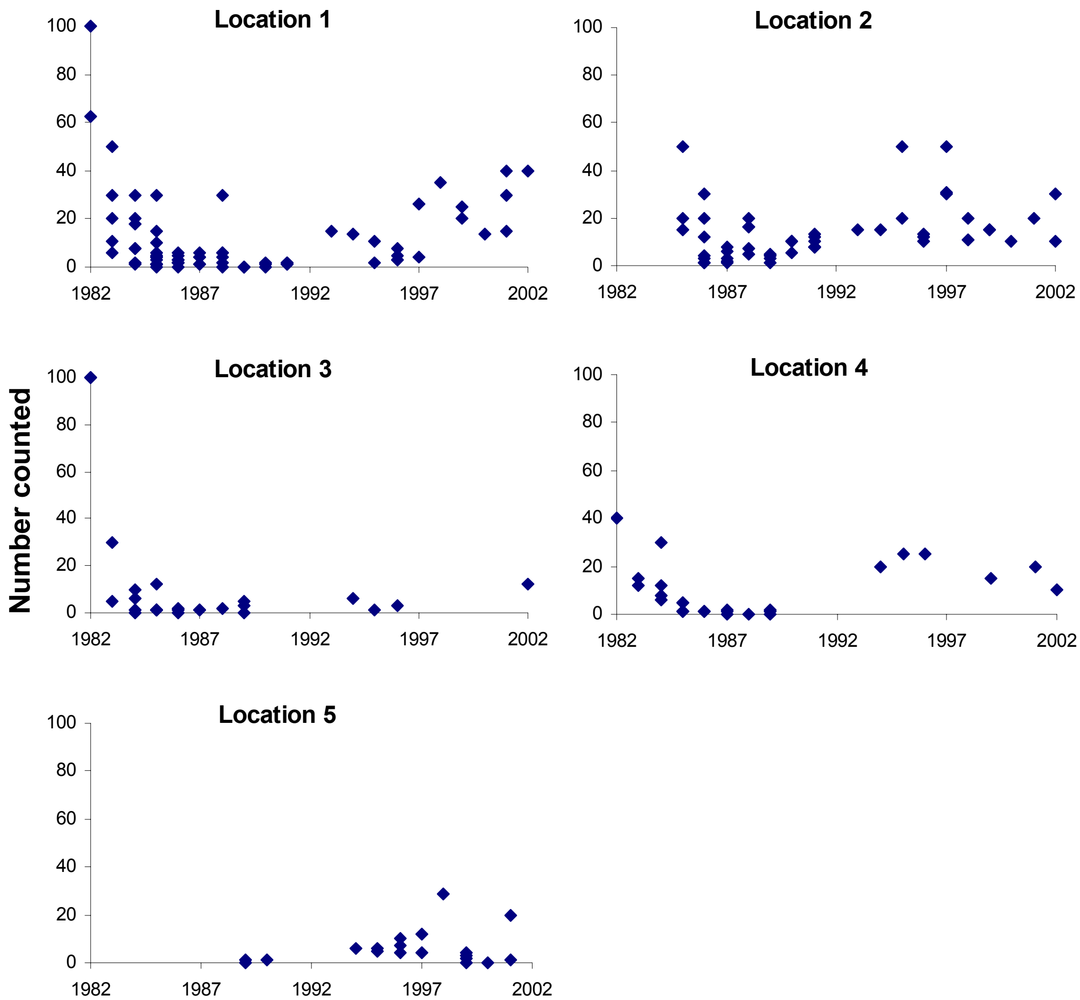

Figure 1. Number of goliath grouper observed at each of five artificial reefs in the eastern Gulf of Mexico, from 1982 to 2002.

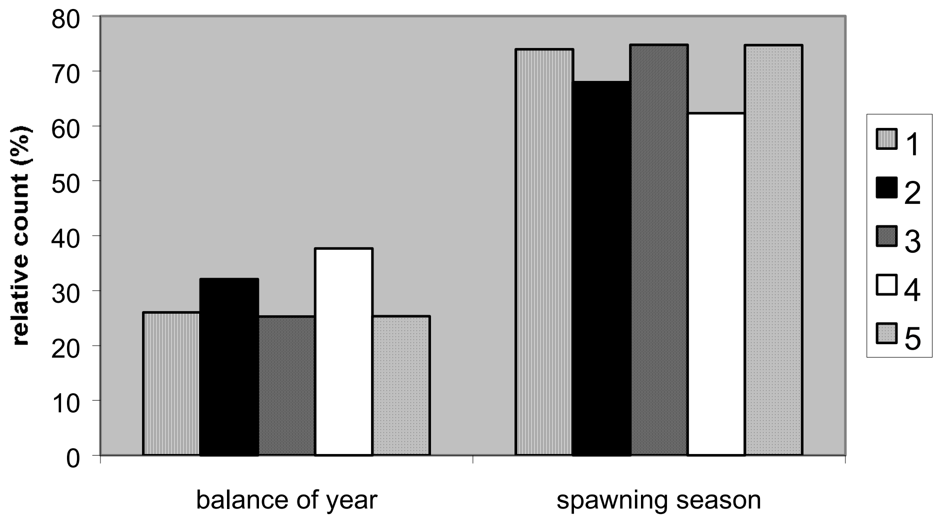

Figure 2. Relative number of goliath grouper counted during and outside the spawning season, broadly represented from June-October, each of five artificial reefs in the eastern Gulf of Mexico from 1982-2002. Only those years (N=5) that had observations in both seasons were included.

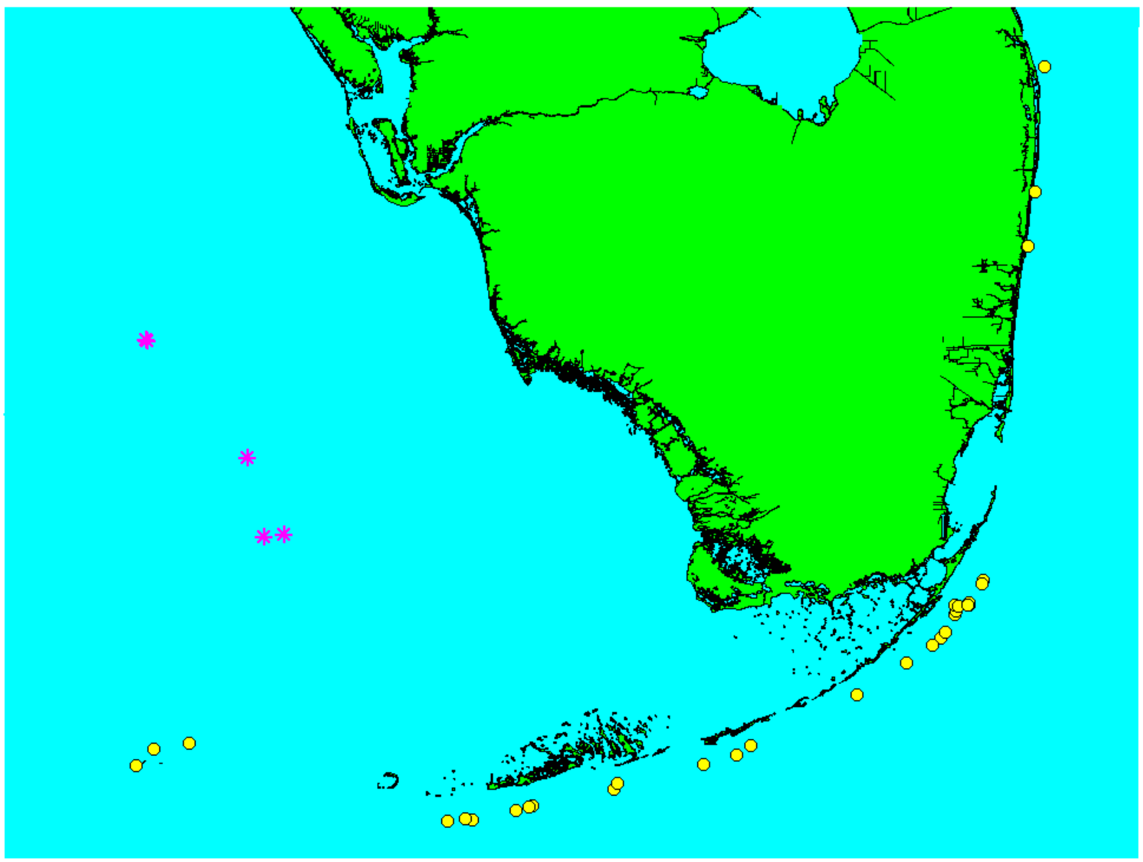

Figure 3. Survey locations for two diver censuses: * = artificial structures in the eastern Gulf of Mexico where goliath grouper were observed from 1982-2002; o = locations where the Reef Education and Environmental Foundation’s volunteer divers observed goliath grouper from 1994-2002.

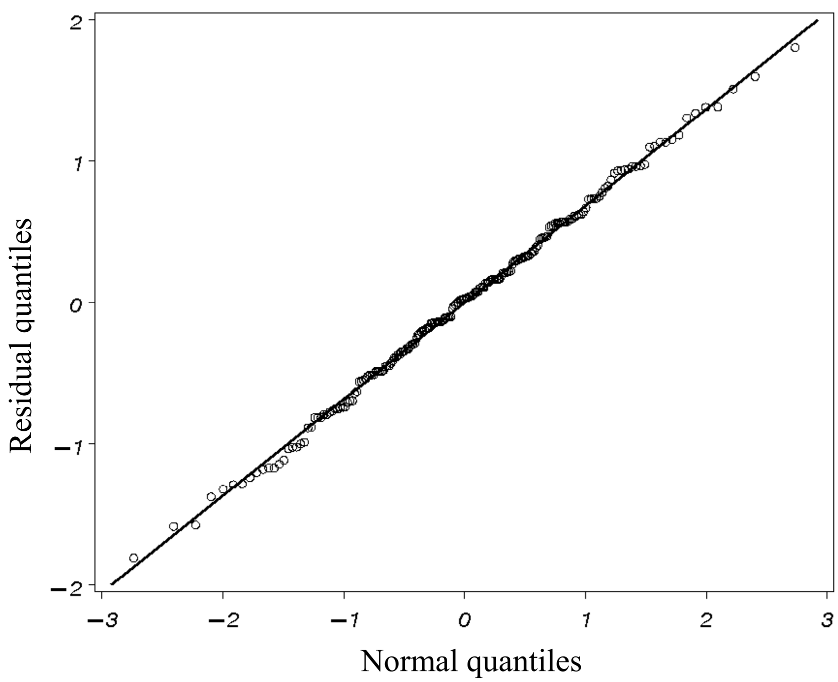

Figure 4. Quantile-quantile plot of the residuals from the GLM fit to the DeMaria count data (circles) compared with a normal distribution with mean zero and standard error 0.685 (line).

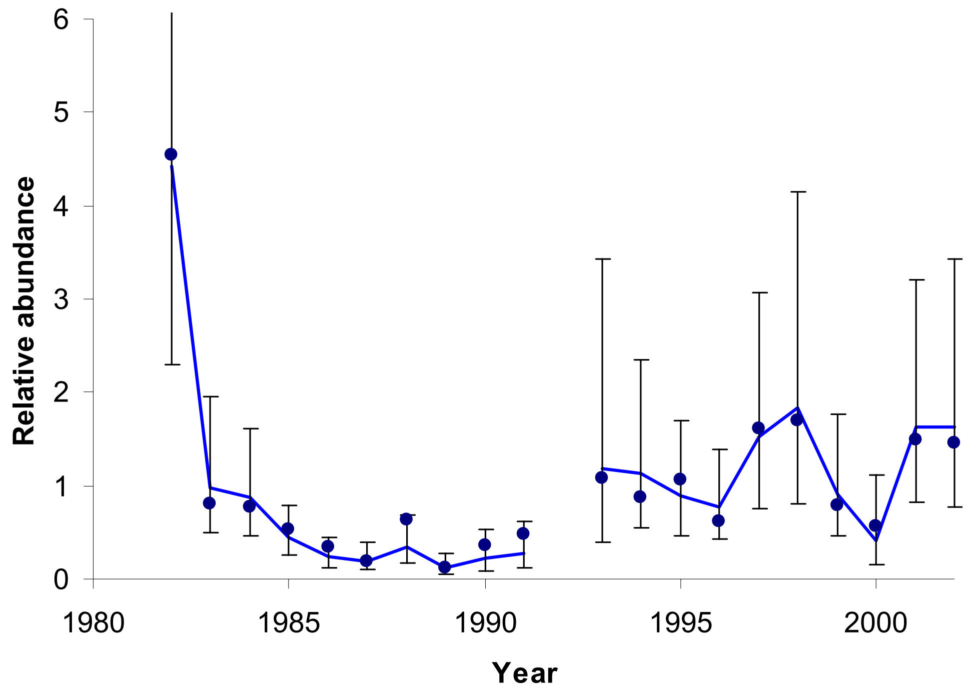

Figure 5. Relative standardized counts of goliath grouper (line) with approximate 95% confidence intervals compared with the corresponding nominal index (circles) from Captain DeMaria's logbook of goliath grouper observations at four artificial structures in the eastern Gulf of Mexico from 1982-2002.

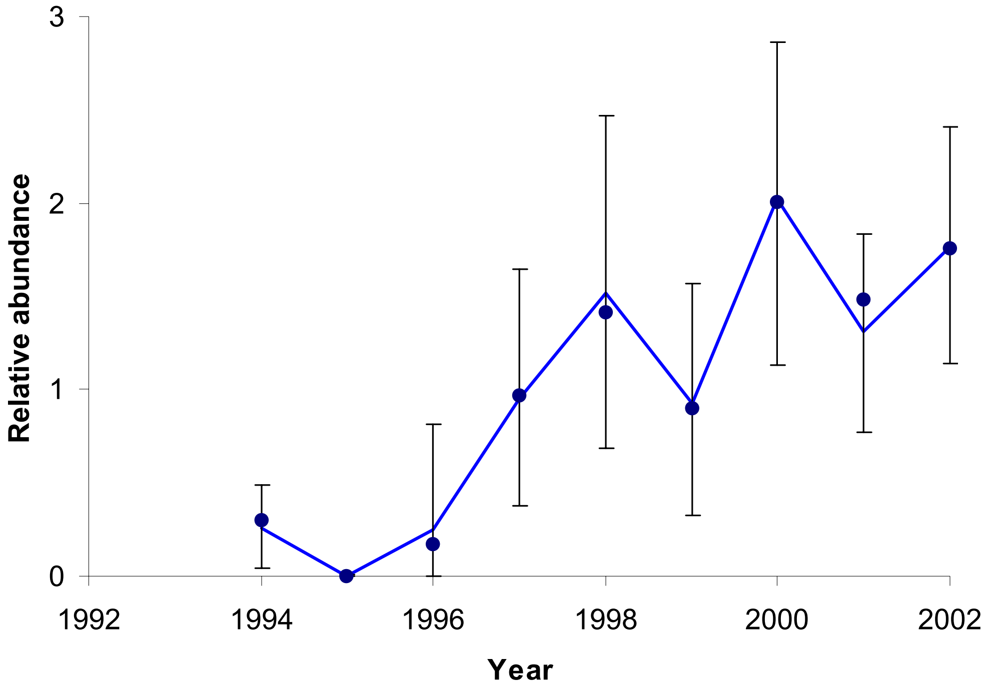

Figure 6. Relative standardized counts of goliath grouper (line) with approximate 95% confidence intervals compared with the corresponding nominal index (circles) from the REEF database of diver observations of goliath grouper in Florida, U.S.A., from 1994-2002.

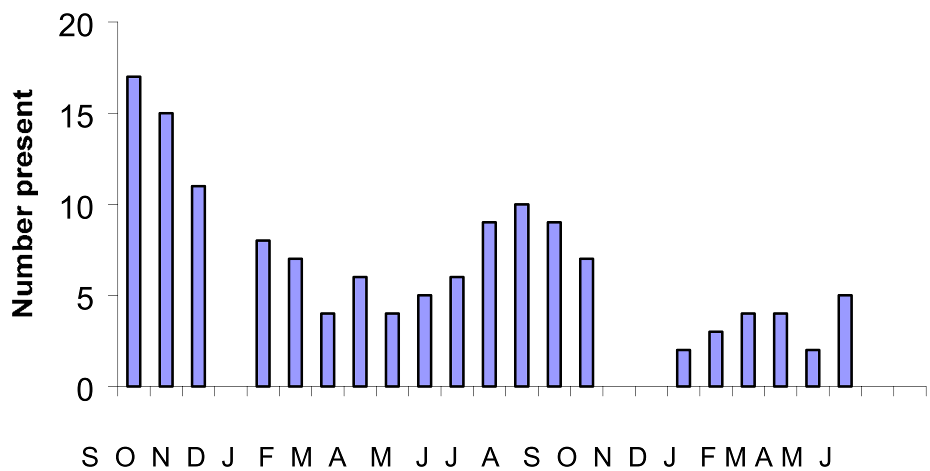

Figure 7. Number of acoustic-tagged goliath grouper detected each month on the Baja California wreck in the eastern Gulf of Mexico (September 2000 to June 2002).

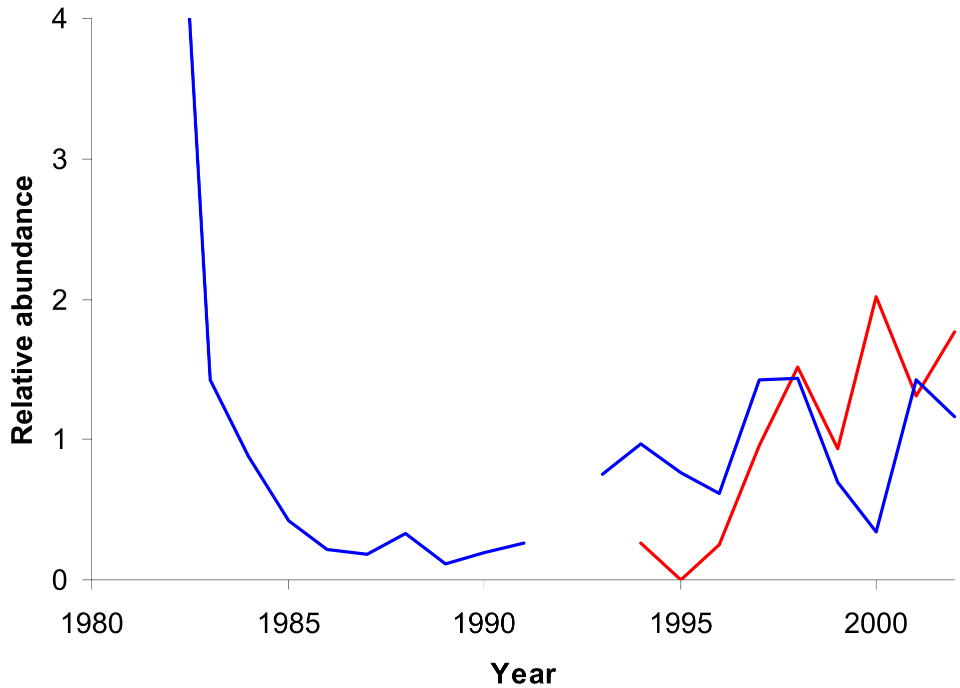

Figure 8. Comparison of standardized counts of goliath grouper from DeMaria's logbook and the REEF database normalized to the 1994-2002 means. Note that both indices are presented relative to their respective annual means. The number of goliath grouper counted on the DeMaria sites is typically an order of magnitude greater than on most of the REEF sites.